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DATE: June 4, 1956

SUBJECT: Cross Section Program at Oak Ridge
National Laboratory

TO: Members of Nuclear Cross Section Advisory Group

FROM: J. L. Fowler and J. A. Harvey

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Oak Ridge National Laboratory

May 29, 1956

To: Members of the NCSAG

From: J. L. Fowler and J. A. Harvey

Subject: Cross Section Program at ORNL

I. High Voltage Group

Fission Cross Section of U^{234} -- R. W. Lamphere.

The fission cross section of U^{234} relative to U^{235} has been re-measured from threshold up to 3.0 Mev. The extrapolated threshold is found to be 250 kev, although measurements have been made at energies down to 70 kev where the cross section is of the order of 14 mb. Additional structure has been found at 330 kev and in the range 0.8 to 1.6 Mev.

Differential Elastic Scattering of Neutrons
from C^{12} and F^{19} -- J. E. Wills, Jr.

This work has been reported in a paper given at the Washington meeting of the American Physical Society.¹ Also a preliminary draft of a paper which gives final results has been written with an abstract as follows:

"Total cross sections and angular distributions of scattered neutrons were measured in studies of the $C^{12}(n,n)C^{12}$ and the $F^{19}(n,n)F^{19}$ reactions.

Total cross section measurements of high resolution were made in the vicinity of a resonance in the scattering of neutrons from carbon at 2.07 Mev. These measurements, coupled with differential cross section measurements in the same energy range, lead to the assignment of a spin and parity of $3/2^+$, with a width of the order of 11 kev.

Angular distributions of neutrons scattered from carbon measured between 0.66 and 4.10 Mev were analyzed in terms of partial waves and the phase shifts describing the scattering of neutrons from carbon were determined.

Total cross section measurements for fluorine, having resolutions of 20 and 70 kev, indicate the presence of levels at 1.10 and 2.25 Mev, as well as some structure above 3 Mev which have not been previously reported. Angular distributions were measured between 0.66 and 2.92 Mev."

¹ James E. Wills, Jr., Bull. APS, Series II, Vol. 1, No. 4, F3 p. 175 (1956).

Differential Elastic Scattering of Neutrons
from Neon -- H. O. Cohn and J. L. Fowler.

Besides the results reported at the Washington meeting², the technique of observing coincidences between nuclear recoils in a proportional counter and scattered neutrons with an anthracene crystal has been used to investigate the 0.91, 1.31, and the 1.38 Mev levels.³ The parity assignments based on angular distributions are as follows: Odd parity levels 0.91, 1.31, and 1.62; even parity, 1.38 and 1.68 Mev. It is expected that detailed analysis will enable one to assign J values in some cases also. In addition, a new level was found at 1.27 Mev.

² H. O. Cohn and J. L. Fowler, Bull. APS, Series II, Vol. 1, No. 4, F6, p. 175 (1956).

³ H. O. Cohn and J. L. Fowler, Phys. Rev. 99, 1625 (1955).

Neutron Activation of Iodine near 25 kev -- R. L. Macklin.

A paper on this measurement was presented at the meeting of the Southeastern Section of the American Physical Society with an abstract as follows:

"The cross section for $I^{128}(n,\gamma)I^{129}$ (25 min. β emitter) has been measured with a standardized antimony-beryllium neutron source. NaI(Tl) crystals were activated at measured distances from the source and the beta particles detected by scintillation counting.⁴ Corrections were measured or computed for neutron energy spectrum, source asymmetry, effective center displacement, scattering in NaI(Tl), and beta detection efficiency. The activation cross section found was $0.82 \pm .06$ barns for neutron energies near 25 kev. The early work of Linenberger and Miskel at Los Alamos at several energies gives an interpolated value of about 1 barn with perhaps 0.2 to 0.3 barn uncertainty. The 2.2 barn (± 0.4 barn) value obtained by Hummel and Hamermesh⁵ with an antimony-beryllium source is in disagreement with the present result."

⁴ H. C. Martin and R. F. Taschek, Phys. Rev. 89, 1302 (1953).

⁵ V. Hummel and B. Hamermesh, Phys. Rev. 82, 67 (1951).

$V^{51}(p,n)Cr^{51}$ Cross Section near Threshold -- C. H. Johnson and A. Galonsky.

A manganese sulphate bath has been used to observe the $V^{51}(p,n)Cr^{51}$ cross section from threshold to 700 kev above threshold. Protons from the 3-Mev Van de Graaff bombarded 20-kev vanadium targets, and the bath was activated at six neutron energies from 20 to 700 kev. The activity was compared to that produced by the 27-kev neutrons from a calibrated Sb-Be

source. These six points normalize the yield curve obtained with a set of BF_3 counters in paraffin surrounding the target. The cross section averaged over resonances rises almost linearly over this region. Absolute values are being calculated from the results of the measurements.

Coulomb Excitation -- P. H. Stelson and F. K. McGowan.

The recent results from work on this problem has been reported in an invited paper at meeting of the Southeastern Section of the American Physical Society, as well as in two abstracts at the Washington meeting.^{6,7}

⁶ F. K. McGowan, P. H. Stelson, and M. M. Bretscher, Bull. American Physical Society, Series II, Vol. 1, C1, 164 (1956).

⁷ P. H. Stelson and F. K. McGowan, Bull. American Physical Society, Series II, Vol. 1, C2, 164 (1956).

The $\text{Si}^{28}(\text{p}, \text{p}'\gamma)\text{Si}^{28}$ Reaction -- H. B. Willard, J. K. Bair, H. O. Cohn, and J. D. Kingston.

An abstract on this reaction presented at the meeting of the Southeastern Section of the American Physical Society, Fisk University, Nashville, March 29-31, 1956, is as follows:

"Angular distributions (with respect to the incoming proton) of the 1.78-Mev gamma ray produced by inelastic scattering of protons by Si^{28} have been measured at and in between each of the 8 resonances previously reported.⁸ The detector was a 3" x 3" NaI crystal located 50 cm from a 2-kev thick Si^{28}O_2 target. For this particular case the spin, but not the parity of the levels formed in the compound nucleus P^{29} , can be inferred. An absolute zero degree differential cross section at the peak

of the 3.10-Mev resonance has been obtained by two independent methods yielding the value 64 ± 12 millibarns/steradian. A run with points spaced less than 1 kev apart revealed 5 additional very narrow, low-intensity resonances at 2.64, 3.88, 3.93, 3.97, and 4.93 Mev."

⁸ Cohn, Bair, Kington, and Willard, Phys. Rev. 99, 644A (1955).

Measurements of Relaxation Times of Subcritical
Reactor by Pulsed Neutron Techniques -- E. C. Campbell and P. H. Stelson.

Additional measurements of the decay constant of the fundamental mode of an enriched homogeneous subcritical U^{235} - H_2O reactor have been made. Reports on this work were presented at the Washington meeting of the American Physical Society⁹, and at the Chicago meeting of the American Nuclear Society.

⁹ E. C. Campbell and P. H. Stelson, Bull. American Physical Society, Series II, Vol. 1, J9, 183 (1956).

Millimicrosecond Time-of-Flight Spectrometry -- W. M. Good, J. H. Neiler, and J. H. Gibbons.

An area analysis has been made of the Al 5.6-kev resonance and two of the selenium resonances, viz., 4.25 and 4.95 kev. The results, respectively, of the energy, σ_0 , Γ_{exp} , $\Gamma_{by\ area}$, for aluminum are 5.6 kev, 2.9 barns, 450 volts, 20 volts, and for selenium are 4.25 kev, 34.5 barns, 300 volts, 50 volts, and 4.95 kev, 33 barns, 400 volts, 50 volts. In this analysis it was assumed that the selenium resonances are in Se^{80} .

Fabricated B^{10} of 50% greater density is being acquired to improve the resolution below 10 kev and further measurements are awaiting this acquisition. Procurement is under way for separated isotopes of lead, lanthanum,

yttrium, titanium, and potassium, as well as others. A feasibility experiment has been done to determine whether it would be possible to observe resonant capture gamma rays. The resonance chosen was the 5.6-kev resonance in aluminum and the capture γ -rays were barely detectable.

II. Fast Chopper Time-of-Flight Spectrometer -- J. A. Harvey and R. C. Block.

Two neutron time-of-flight spectrometers have been designed for installation at the LITR and ORR. One spectrometer will be used to measure partial neutron cross sections (such as scattering, fission, and capture) with a resolution of 0.08 μ sec/meter. This spectrometer, now under construction, will consist of a 16-inch diameter monel rotor, a 45-meter flight path, a bank of BF_3 counters, and a 256-channel, magnetic-core, time analyzer. The other spectrometer will have a resolution of 0.01 μ sec/meter (equivalent to an energy spread of 0.3 kev at 10 kev) and will be used at the ORR for total cross-section measurements. This high-resolution spectrometer will have a 180-meter flight path and a 2048-channel time analyzer. Construction of this second rotor is being delayed until the first rotor is tested. Various high-efficiency neutron detectors are being investigated.

The old time-of-flight spectrometer is now operating and is being used for total cross-section measurements of separated isotopes and long-lived fission products.

III. Applied Nuclear Physics Division

Number of Neutrons per Fission for Pu^{241} -- E. G. Silver and G. De Saussure.

Present measurements result in a value of 1.32 ± 0.05 for ratio $\nu(\text{Pu}^{241})/\nu(\text{U}^{235})$ averaged over a pile neutron spectrum from the graphite

reactor. Using the value of 2.46 for $\nu(U^{235})$ from BNL-325, $\nu(Pu^{241})$ is 3.25 ± 0.12 . Further measurements are being made in order to determine the ratio to an accuracy of 1%. More highly enriched Pu^{241} would improve the accuracy of the ratio.

Fission Product Gammas -- R. W. Peelle, W. Zobel, and T. A. Love.

The fission product photon spectrum has been studied with a multiple scintillation gamma-ray spectrometer. The energy spectrum has been arbitrarily divided into six energy groups from 0.28 to 5 Mev. The decay with time of each energy group has been measured from about 1 to 1600 μ sec. The different energy groups show somewhat different time decays. The results have been analyzed to give preliminary values of 3.3 ± 0.8 for the number of photons per fission and 3.6 ± 0.9 Mev for the energy per fission in the energy range from 0.28 to 5 Mev and in the time range from 1 to 1600 μ sec.

The energy spectrum has also been measured with a rotating enriched uranium belt. The data result in a value of 4.2 ± 0.8 for the number of photons per fission and 4.8 ± 1.0 Mev for the energy per fission in the energy range from 0.35 to 5.8 Mev and the time range from a few seconds to a few hours.

IV. Chemistry and Analytical Chemistry Divisions

Thermal Neutron Activation Cross Sections -- W. S. Lyon and S. A. Reynolds.

The program of measuring thermal cross sections is continuing. The following table summarizes the pile neutron cross sections (10% accuracy) obtained in the past 6 months.

<u>Target Nucleus</u>	<u>σ_{act} (barns)</u>
$^{12}\text{Mg}^{26}$	0.027
$^{19}\text{K}^{41}$	1.28
$^{20}\text{Ca}^{44}$	0.78
$^{24}\text{Cr}^{50}$	15.2
$^{28}\text{Ni}^{64}$	1.46
$^{29}\text{Cu}^{63}$	4.1
$^{30}\text{Zn}^{64}$	0.42
$^{30}\text{Zn}^{68}$	0.101
$^{31}\text{Ga}^{71}$	6.2
$^{33}\text{As}^{75}$	6.7
$^{35}\text{Br}^{81}$	4.1
$^{37}\text{Rb}^{85}$	0.91
$^{40}\text{Zr}^{94}$	0.069
$^{40}\text{Zr}^{96}$	0.050
$^{42}\text{Mo}^{98}$	0.58
$^{46}\text{Pd}^{108}$	13.6
$^{47}\text{Ag}^{109}$	5.3
$^{55}\text{Cs}^{133}$	43
$^{56}\text{Ba}^{130}$	10.5
$^{57}\text{La}^{139}$	8.2
$^{73}\text{Ta}^{181}$	39
$^{74}\text{W}^{184}$	2.1
$^{78}\text{Pt}^{196}$	0.79

Several of these nuclides, such as Ag^{109} , Cs^{133} , and Ta^{181} , have appreciable resonance absorption and, hence, the pile cross sections are somewhat higher than the thermal cross sections. For $1/v$ absorbers with little resonance contribution, thermal cross sections are about 4% less than the above pile cross sections.

The thermal activation cross section of Y^{89} was measured to be 1.26 ± 0.08 barns. This is in good agreement with the "best value" of 1.28 ± 0.08 barns for the absorption cross section.

Heavy Element Thermal Neutron Cross Sections -- J. Halperin and R. W. Stoughton.

Analysis of data on Th^{233} to obtain the thermal activation cross section and the activation integral is continuing. A preliminary value for the thermal activation cross section of Th^{233} is 1400 ± 200 barns.

Measurements on the resonance activation integral of U^{236} give a preliminary value somewhat higher than the value of 320 barns computed from the resonance parameters.

Pile cross sections of U^{236} and U^{238} have been determined for a highly irradiated MTR fuel element. Preliminary results are 34 barns for U^{236} and 23 barns for U^{238} . The activation integral of U^{236} from these data is nearly 400 barns.

V. Electronuclear Research Division

(n,p) Cross Section Measurements -- H. G. Blosser and T. H. Handley.

A number of measurements of (n,p) cross sections have been made at a neutron energy of 14 Mev by activation techniques. Preliminary results are as follows: Zn^{64} 216 mb; Zn^{66} 80 mb; Ge^{70} 93 mb; Ge^{72} 32 mb; Ni^{61} 91 mb;

Cu⁶⁵ 20 mb, and Ge⁷³ 20 mb.

All of the above values are relative to a $\sigma(n,p)$ of 125 mb for Fe⁵⁶.

An error analysis on the above results is currently underway.

Cross Sections Determined with Nitrogen Ions -- A. Zucker and M. L. Halbert.

Separated magnesium isotopes were bombarded with nitrogen ions, and the neutron transfer cross sections, as a function of energy, have been determined. At 26 Mev the $Mg^{25}(N^{14}, N^{13})Mg^{26}$ reaction has a cross section of 10 ± 2 mb. The cross section for the reaction $Mg^{24}(N^{14}, N^{13})Mg^{25}$ at 26 Mev is $1.8 \pm .5$ mb. Preliminary results have been obtained for the neutron transfer cross section from nitrogen to beryllium. At 26 Mev lab energy the cross section is about .7 mb. Excitation functions have been measured for two nitrogen-sodium reactions. At 26 Mev the cross section for $Na^{23}(N^{14}, \alpha p)P^{32}$ reaction is 94 ± 20 mb, and the cross section for the reaction $Na^{23}(N^{14}, \alpha 2p)Si^{31}$ is $4.4 \pm .9$ mb.

Electromagnetic Separations -- J. A. Martin.

Plutonium Feed Supply

Feed Now On Hand. The plutonium now being processed consists of two batches of different isotopic composition. Batch (A) is the 13% Pu²⁴⁰ feed which has been downgraded slightly by cross-over from the earlier separations of low MWD/T plutonium. Batch (B) was received this spring. Two runs have been attempted but were unsuccessful, because of malfunction of the ion source. The material is now being recovered and repurified. The following table summarizes the feed characteristics and the weight and composition of product anticipated in future runs.

	Isotopic Composition (At. %)				Wt. (gms)*
	Pu-239	Pu-240	Pu-241	Pu-242	
Batch (A)	87.3	11.2	1.3	0.2	100
Expected Product					
Pu-240	17	87	1	--	0.880
Pu-241	21	28	50	1	0.13
Batch (B)	84.3	13.7	1.8	0.2	120
Expected Product					
Pu-240	12	87	1	--	1.20
Pu-241	25	14	60	1	0.17

* Product weights are calculated assuming 7.0% separator efficiency; 90% retention for Pu²⁴⁰; 70% retention for Pu²⁴¹.

New Feed. A new batch of plutonium is expected in mid-August. This is derived from a Pu-Al alloy rod from the same source as the other materials.

The following table gives the expected isotopic composition and amount of product per separation.

	Est. Isotopic Composition (At. %)				Wt. (gms)
	Pu-239	Pu-240	Pu-241	Pu-242	
Feed	75	21	3	1	225
Pu ²⁴⁰ Product	9	90	1	-	3.3
Pu ²⁴¹ Product	14	14	70	2	0.470

MTR Fuel Elements. Minor difficulties have developed in the MTR Pu fuel element fabrication program which will delay the introduction of the first elements into the MTR by an additional thirty days. The source of trouble has been determined and changes in fabrication technique are being investigated. If the changes are successful, the first element should be ready for irradiation in mid-July of this year. The first isotope separation of the MTR plutonium will probably be completed about midyear of 1957, yielding Pu²⁴¹ of about 90% purity and Pu²⁴⁰ of 95% purity.

LIIS (Low Intensity Isotope Separator)

Testing of the LIIS continues as time permits. Additional work is required to improve the consistency of operation and to gain operating experience. Present performance is 4% process efficiency at an estimated one-mass-unit enrichment of 20. A separation of the composite of batches P1-41, P2-41, P3-41, P7-41, and PS4-41 (see inventory) should yield 2 to 4 milligrams of 90% pure Pu²⁴¹ containing about 5% each of Pu²³⁹ and Pu²⁴⁰.

Scheduling

Processing Time. As an aid in understanding the time schedule we have tabulated the time required for a few of the operations.

	Time (days)
Separation	2-3
Recovery of unseparated charge, purification and chlorination	90
Precipitation and chlorination of new material	15-21
Recovery of product from pockets, purification, and assay	15-21
Complete removal of a particular material type from the system	150-200

The latter operation cannot be conducted simultaneously with the other operations without affecting them markedly. During the past two years the recovery of low irradiation level material from the system has necessarily slowed the processing of the high Pu²⁴⁰ content batches appreciably.

Present Schedule. The following schedule has been adopted for the summer and early fall.

<u>Time</u>	<u>Batch</u>
June 25 - June 30	(A)
August 6 - August 10	(B)
August 27 - August 31	New 21% Pu ²⁴⁰ Batch
September 15 - October 15	Low Intensity Separation for 90% Pu-241

One or two more separations of the 21% material will be completed before cleanup of the system prior to introduction of the MTR material.

Inventory

An inventory of the heavy element isotopes available at ORNL is to be given in an ORNL document. A preliminary draft will be available at the meeting. Additional information concerning U²³³ and Am²⁴¹ can be obtained through J. H. Gillette or H. F. Stringfield, and for the other isotopes, from R. S. Livingston or J. A. Martin.

Demand for Isotopes.

We have the impression that the demand for enriched plutonium isotopes is not properly represented by the requests received. Most potential isotope users realize that the supply is limited and for that reason requests

are normally only for amounts related to the quantity on hand. It would be extremely helpful if some expression of the long-term demands could be gathered by the Committee.

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